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(54) Abstract Title
Optical detection of icing conditions

(57) A device for detecting the severity of icing conditions, that can be carried on board an aircraft. An optical beam is provided to illuminate an external volume V, and light backscattered from water particles flowing through the volume V is collected by the system 2, 12 and 22.

A signal processor computes the severity of the icing conditions.

A second embodiment uses a polarised beam, and differentiates between solid and liquid water particles by separating the backscattered light into two beams of different polarisation, and analysing the intensity of each beam.

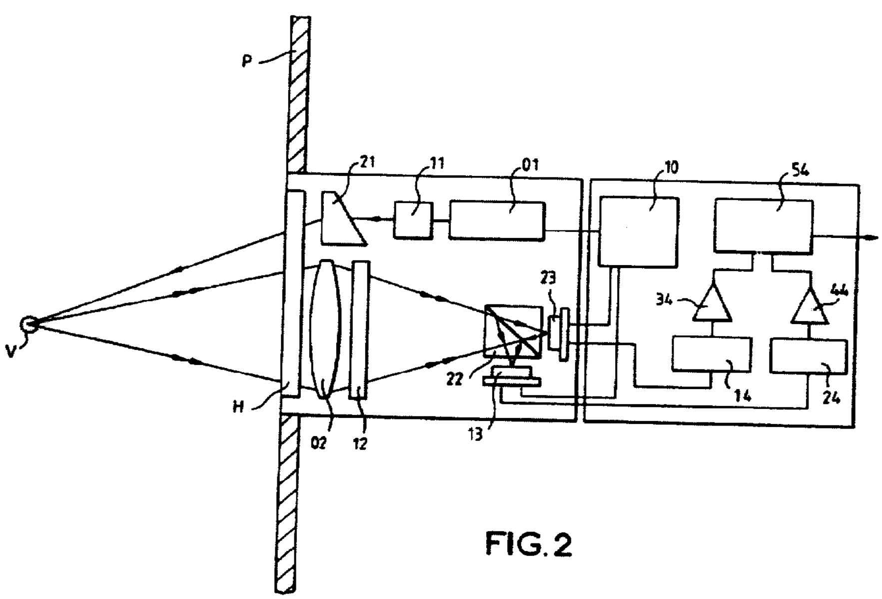

FIG.2

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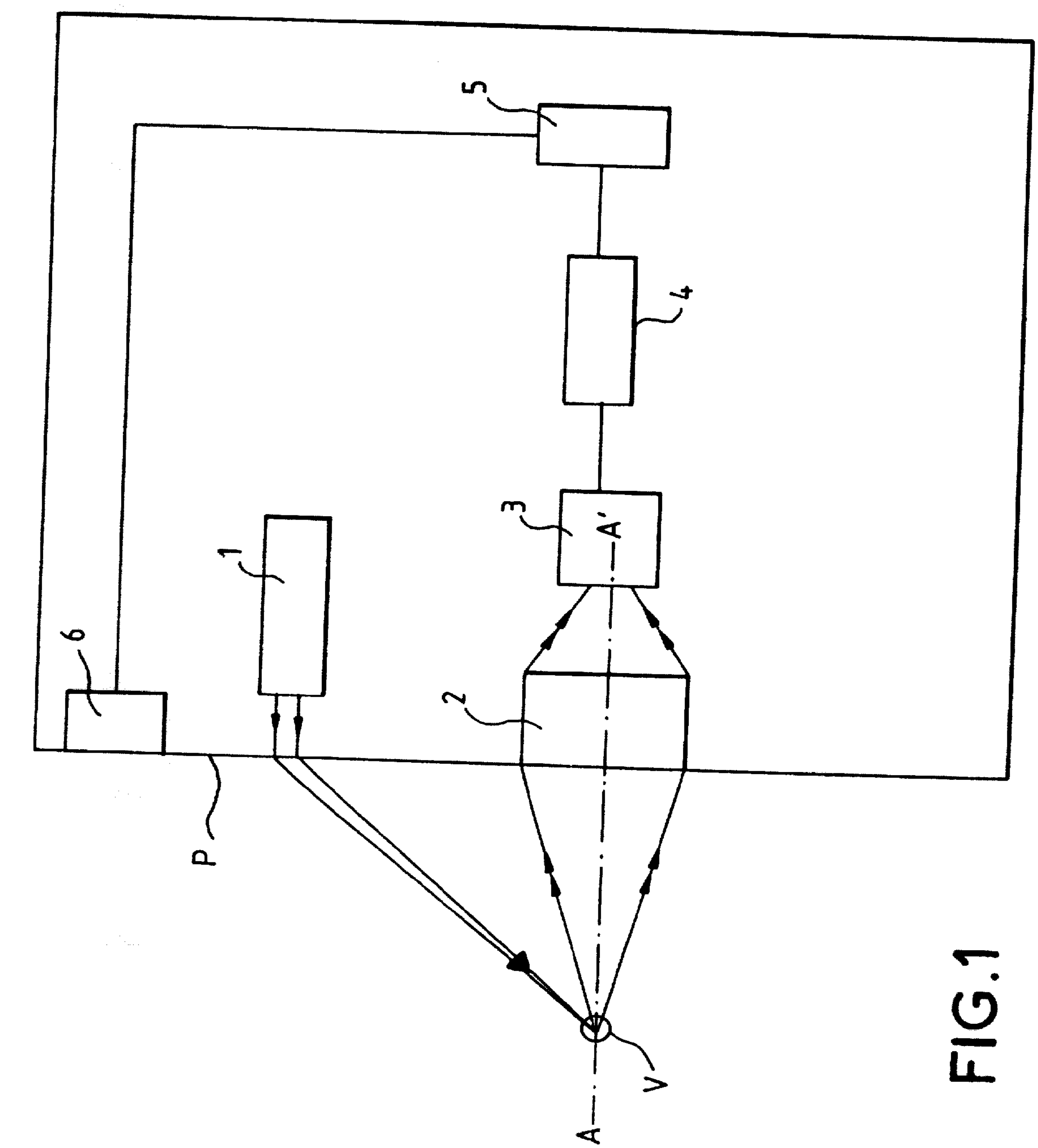

FIG.1

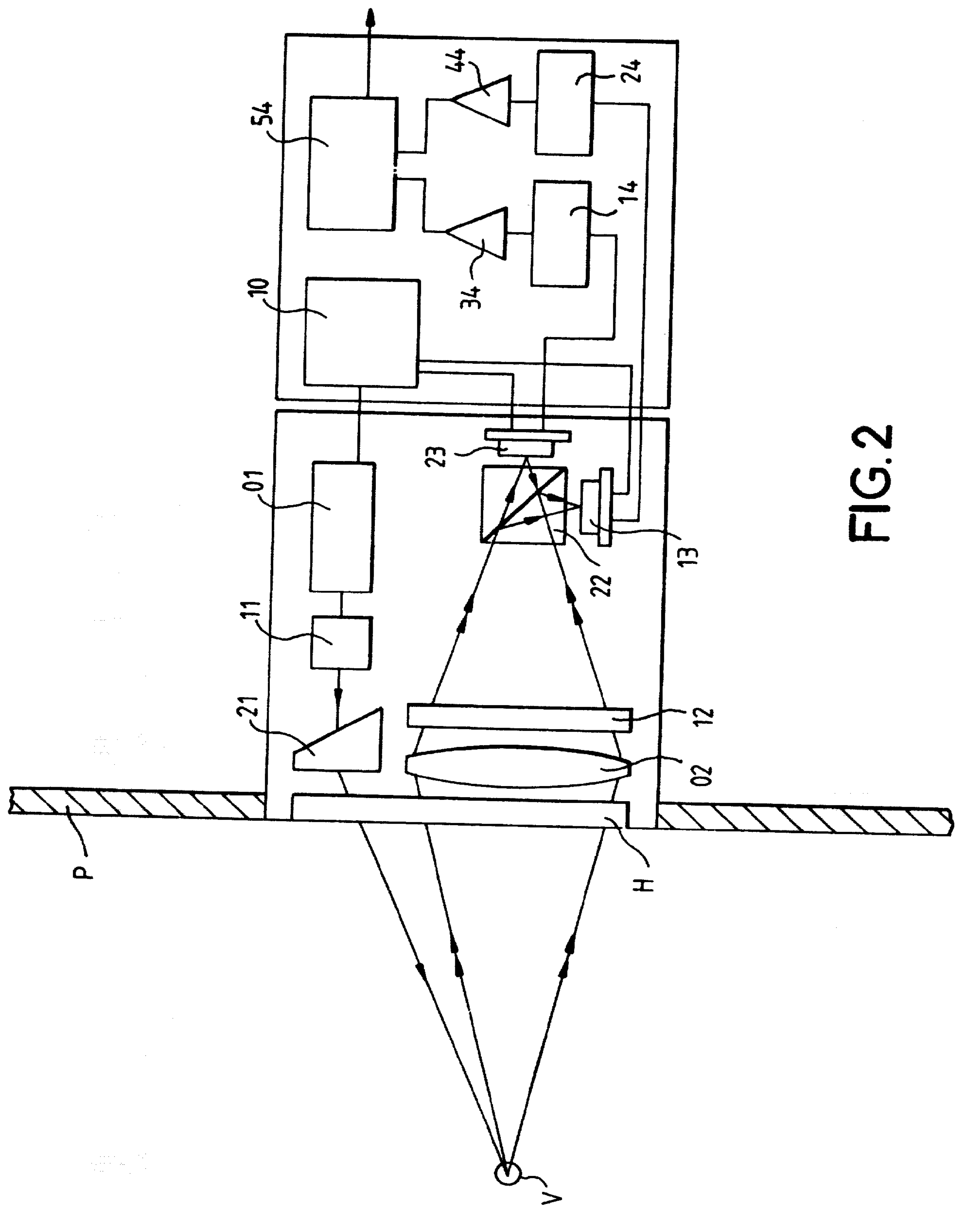

FIG.2

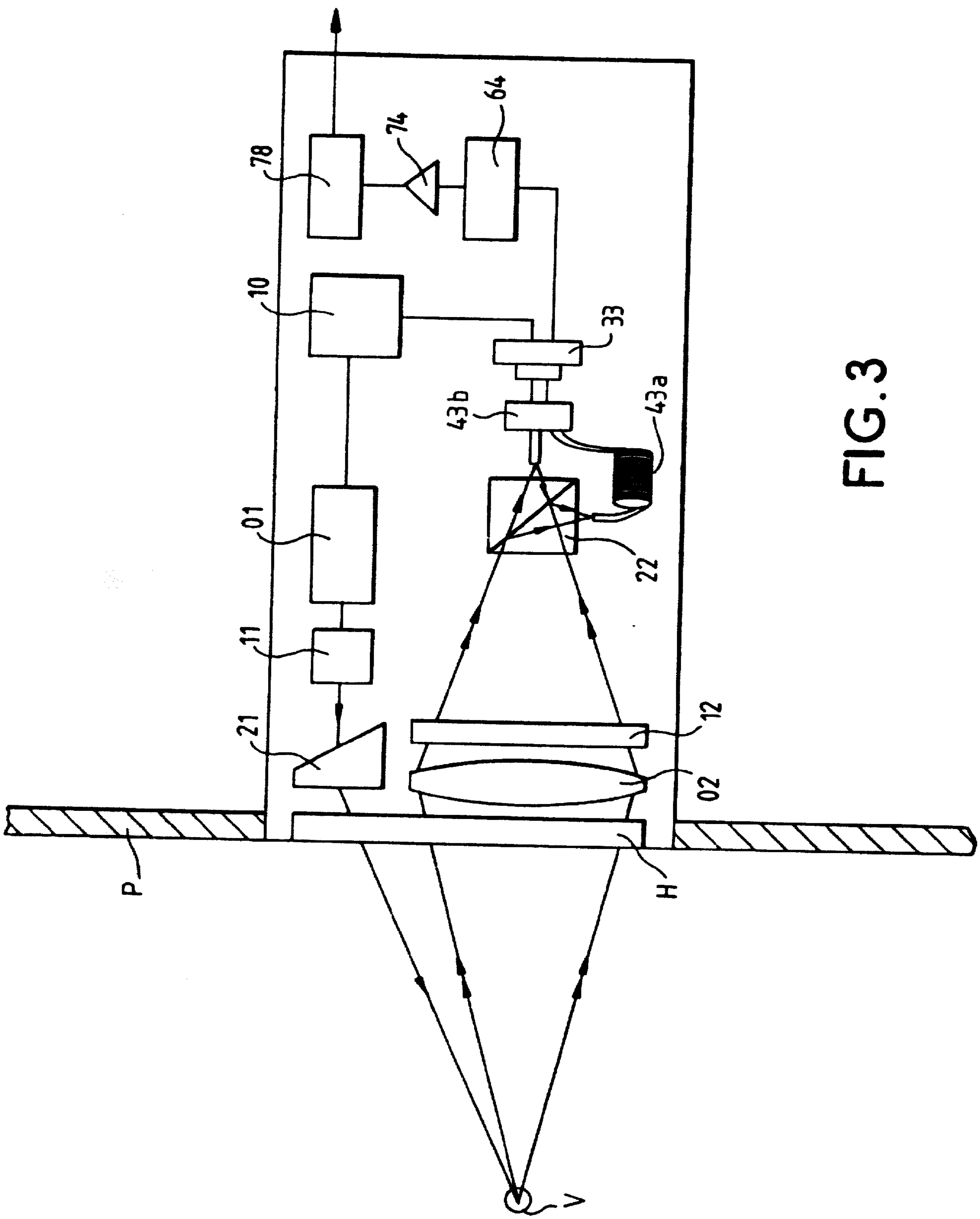

FIG.3

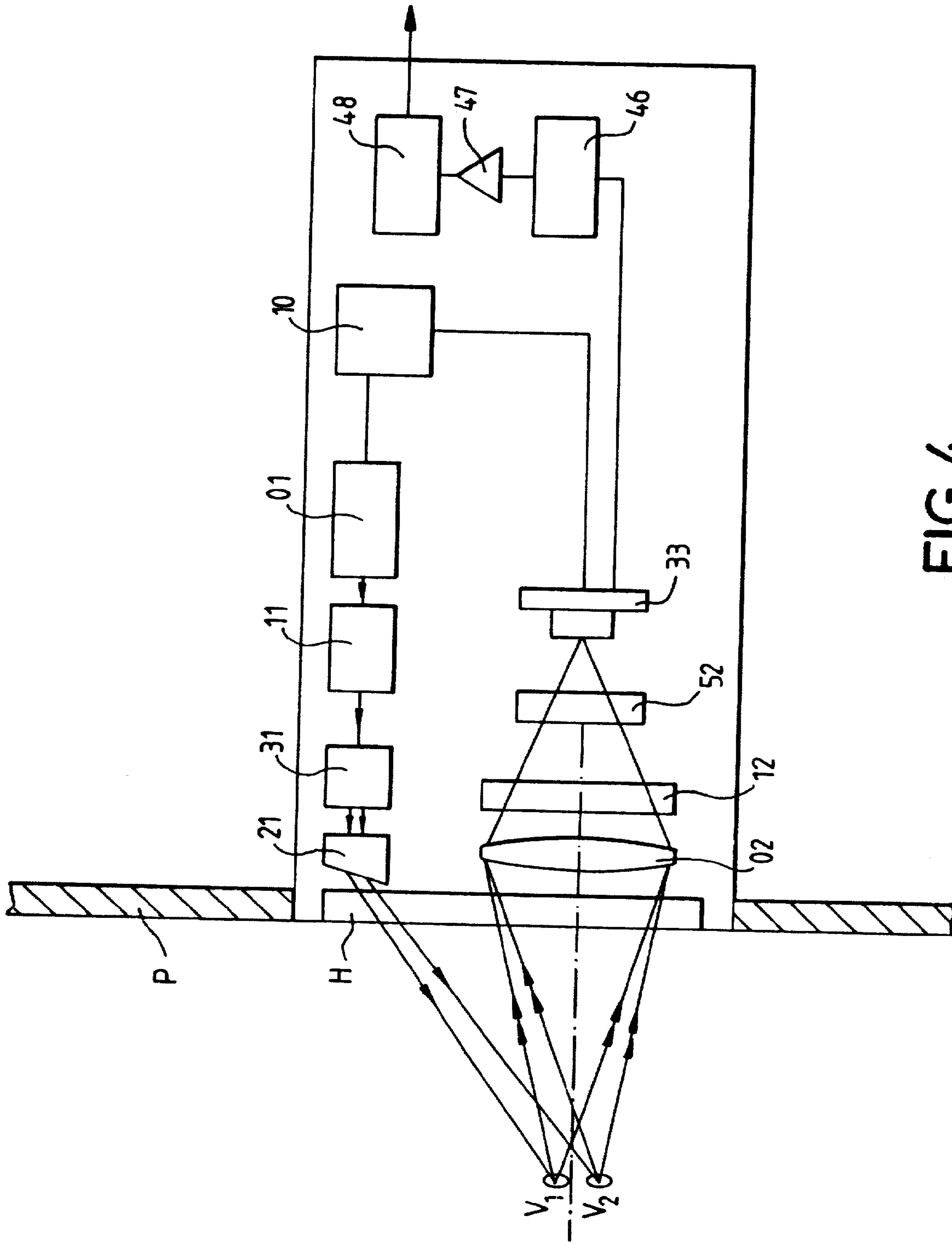

FIG.4

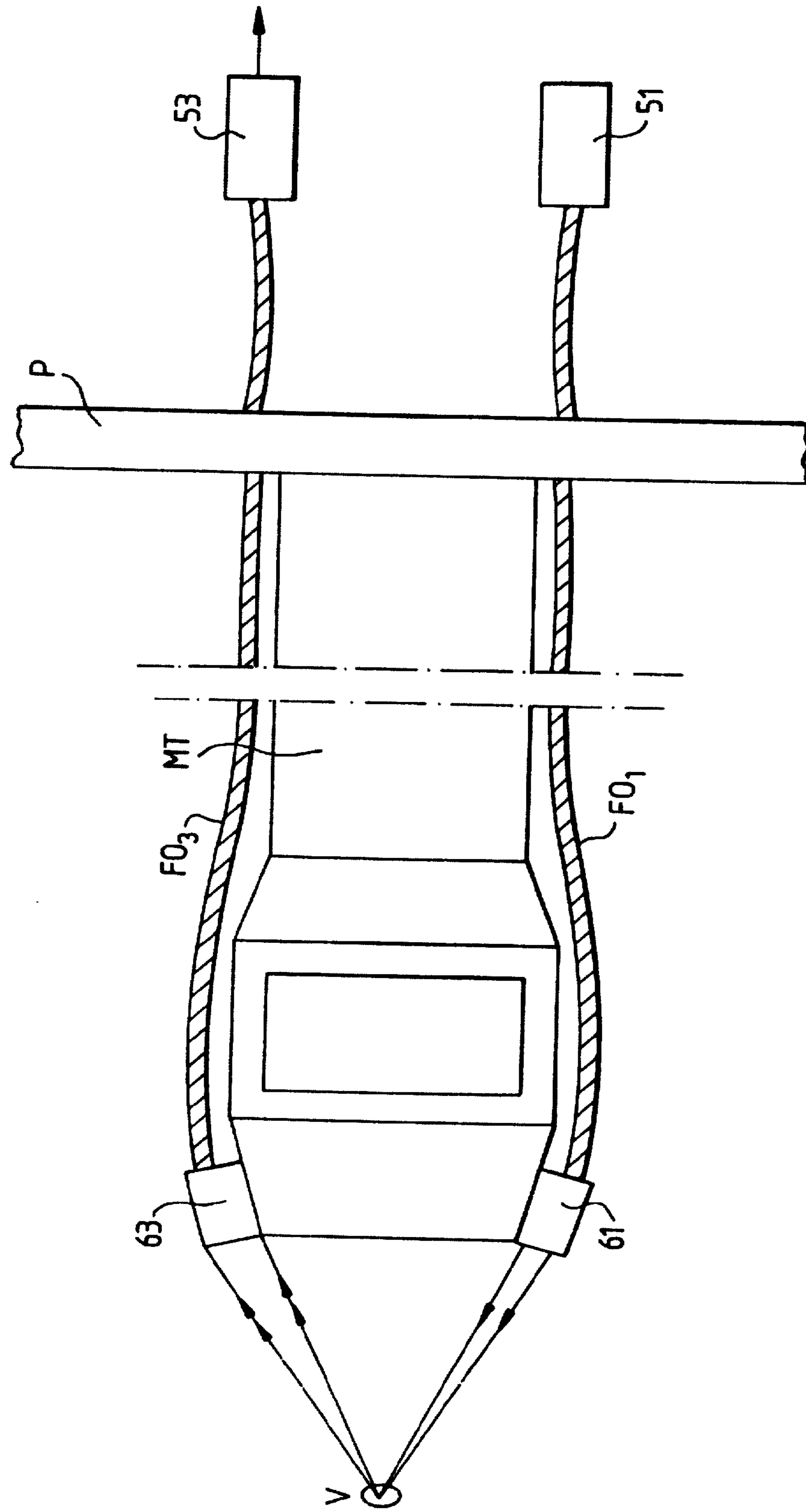

FIG. 5

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OPTICAL DEVICE FOR THE DETECTION OF ICING CONDITIONS ON AIRCRAFT

The field of the invention is that of the detection of icing conditions for aircraft. The problem of the rapid formation of ice is presently still a serious one capable of causing accidents when it occurs suddenly and when it has not been possible to detect it earlier.

The measurement of safety in relation to icing conditions depends on the following parameters:

- the temperature;
- the severity of the icing conditions which is equal to the water concentration multiplied by the speed of the aircraft.

At present, aircraft are equipped with temperature probes and their speed is known, but the severity of the icing conditions is not determined.

The current systems of measurement detect the appearance of ice but do not determine the icing conditions. In particular, the aircraft may be equipped with bar type protuberances. When the bar gets iced up, electrical power is sent to de-ice it, a luminous indicator having informed the aircraft pilot that it is time to activate the de-icing equipment.

There are similar predictive devices in existence. The operation of these devices consists in constantly heating the bar. The electrical power needed for the heating increases when water particles come into contact with said bar. The tracking of changes in the amount of electrical power that has to be used provides an indication of the icing conditions.

Nevertheless, in the prior art devices, it is necessary to use a protuberance in addition to the existing temperature probes, whereas there is a constant search for improvement in the aerodynamic features of the aircraft.

This is why the invention proposes an optical device for the detection of icing conditions that works through an optical window of the aircraft or even through the temperature probe as shall be explained further below.

According to one aspect of this invention there is provided an optical device for the detection of icing conditions, the device being placed on board an aircraft, wherein the device furthermore comprises:

- means to emit an optical beam to create at least one illuminated external volume of measurement through which there circulates a flow of air charged with water particles;
- a collector optical system for the collection of at least a part of the light beam back-scattered by the water particles (the external volume of measurement being located on the optical axis of said collector optical system);
- means for the photodetection of back-scattered optical beams;
- a device for the processing of the signal delivered by the photodetection means to compute the severity of the icing conditions;
- means for providing information on icing conditions on the basis of the severity of the icing conditions.

Advantageously, the emission means may comprise a compact, light-weight source of the laser diode type because the device of the invention does not require the use of high-powered optical systems, i.e.: a few mWatts are sufficient. It is thus possible to make the probe work without causing any ocular risk to an individual who places his or her eye in the emitted optical beam.

According to an alternative embodiment of the invention, it is possible to carry out a very fine analysis of the icing conditions by differentiating between liquid water particles in a supercooled state (at a temperature below zero) and solid water particles. Indeed, the liquid water particles represent an increased danger, inasmuch as they get frozen instantaneously on the aircraft when they re-enter into collision with it. This analysis relies on the fact that drops of supercooled water preserve linear polarisation while ice crystals depolarise light.

To implement this analysis, an optical device which embodies the invention may comprise a polarisation separator in the collector optical

system in order to isolate the back-scattered optical beams that have different types of polarisation from one another, the emission means having delivered a polarised optical beam upline. These two back-scattered optical beams may be detected simultaneously by two photodetectors or else they may be detected by a single photodetector, after having been separated in time.

The optical device may also comprise, at the emission means, a birefringent element capable of generating two optical beams with different types of polarisation in slightly different directions and thus two offset illuminated volumes of measurement and hence two back-scattered optical beams that are also offset.

According to one alternative of the invention, the optical device can be integrated into the aircraft and may work through an optical window.

According to another alternative of the invention, the optical device may be integrated into the temperature probe. A configuration of this kind comprises:

- an optical fibre for emission that connects the emission means integrated into the aircraft up to the external end of the temperature probe;
- an optical fibre for reception connecting the external end of the temperature probe up to the signal reception and processing means integrated into the aircraft.

The invention will be understood more clearly and other advantages shall appear in the following description given on a purely non-restrictive basis with reference to the appended drawings, of which:

- Figure 1 illustrates a drawing of the optical device for the detection of icing conditions;
- Figure 2 illustrates a first exemplary optical device for the detection of icing conditions comprising means differentiating between the liquid water particles and the solid water particles with two photodetectors, and two photodetectors;

- Figure 3 illustrates a second exemplary optical device for the detection of icing conditions comprising means for differentiating between the liquid water particles and the solid water particles, and one photodetector;
- figure 4 illustrates a third exemplary optical device for the detection of icing conditions comprising means for differentiating between the liquid water particles and the solid water particles and a birefringent element and a polariser;
- figure 5 illustrates a configuration in which the device of the invention is integrated into the temperature probe.

The optical device for the detection of icing conditions is essentially constituted in its basic configuration, as illustrated in figure 1, by::

- means 1 for the emission of an optical beam directed towards the outside of the aircraft, through the skin of the aircraft P, so as to create an illuminated volume of measurement V, crossed by a flow of air charged with water particles;
- a collector optical system 2 for the collection of at least part of the optical beam back-scattered by the water particles;
- means 3 for the photodetection of the back-scattered beam;
- a device 4 for the processing of the signal delivered by the photodetection means 3 so as to determine the concentration of water particles in the air;
- means 5 for providing information on the icing conditions on the basis of the data delivered by the device 4 and the temperature data delivered by a temperature probe 6.

According to a first exemplary optical device according to the invention, the collector optical system comprises means of differentiating between liquid water particles and solid water particles by analysis of the polarisation. An exemplary device of this kind is illustrated in figure 2.

The emission means may comprise a polarised laser diode 01 emitting for example in the visible or near infra-red range (between 400 nm and 1 500 nm), a collimation optical unit 11 and a deflection prism 21, so as

to create an illuminated volume of measurement V on the optical axis AA' of the collector optical system, through the porthole window H of the aircraft, located on the skin P of the aircraft.

Typically, the emission means can emit light outside the skin of the aircraft, at a distance of approximately 100 mm, making it possible to carry out measurements outside the boundary layer of the aircraft (the area in which measurements would not be representative) while preserving a reasonable level of emitted power, a volume of polarised light whose dimensions are smaller than one mm, namely a value below which it can be shown that the probability of having two particles simultaneously in the volume of measurement is almost zero.

The collector optical system may comprise a focusing optical unit 02 with a small diameter (10 to 20 mm) and a narrow-band optical filter module 12 (working typically in the range of about 10 nm) that enables the filtering of solar illumination. The collector optical system may also comprise a polarisation separator 22, which may be either a polarising separator cube or a birefringent separator.

In this alternative, the photodetection means comprise two photodetectors 13 and 23 which recover cross-polarised optical beams. The polarisation of the optical beam back-scattered by the liquid water particles is identical to that of the incidental optical beam. A signal I_{1L} relating to this back-scattered optical beam is recovered at the photodetector 13. On the other hand, the photodetector 23 recovers a real signal relating to a cross polarisation ($I_{2L} = 0$).

The polarisation of the optical beam back-scattered by the solid water particles is modified in relation to that of the incidental optical beam. The two photodetectors 13 and 23 recover signals I_{1S} and I_{2S}, when a particle passes into the volume of measurement.

The device embodying the invention comprises the power supplies 10 needed for the emission means and the reception means.

The signal processing device comprises:

- means 14 and 24 for filtering the signals received by the photodiodes 13 and 23;
- variable gain electronic amplification means 34 and 44 for the amplification of the signals;
- an electronic circuitry 54 carrying out the mathematical processing of the received signals (summation, comparison of the two channels, computation of the severity of the icing conditions).

The main characteristics of the signal are:

- its temporal width which depends on the speed of the particle and on the dimensions of volume of measurement (it duration is equal typically to 1 μs);
- its amplitude which depends on the size of the particle;
- its rate of polarisation which depends on the shape and hence on the nature of the particle. Indeed, the drops of supercooled water which are spherical in shape preserve the polarisation, whereas the ice crystals depolarise light.

The electronic system placed downline from the photodiodes fulfils the following functions:

- the filtering means 14 and 24 make it possible in particular to decrease the noise;
- the amplification means 34 and 44 may advantageously be variable gain amplification means so as to obtain signals proportional to the volume of the drops of water;
- the electronic circuitry 54 computes the total volume of the drops of water that pass per unit of time, by the summation of the signals obtained on the two channels. It also computes the rate of polarisation by computing the energy ratio between the signals of the two channels and thus determines the nature of the particles.

The electronic circuitry thus makes it possible to obtain knowledge of the quantity of liquid water that passes per unit of time and the nature of this water.

This information together with the temperature information (from the temperature probe 6 of figure 1) thus makes it possible to determine the severity of the icing conditions.

In the exemplary device that has been just described, the emission means and the collector optical system comprise distinct focusing means. According to another alternative of the invention, it is possible to replace the prism 21 and the optical unit 02 by a single field lens placed against the porthole window and centred on the optical axis AA'.

According to a particularly worthwhile device of the invention, the emission and reception means are laid out in such a way that the incidental optical beam has a direction forming an angle known as a 'rainbow' angle of about forty degrees with the optical axis AA'. Indeed, it can be shown that, in this configuration, the drops of water will radiate an intense and strongly polarised radiation towards the receiver part,. This radiation is characteristic of spherical water drops with an optical index of 1.33 (which is characteristic of water).

According to a second exemplary device for the detection of icing conditions, the photodetection means can comprise a single photodetector, enabling the reduction of the filtering and amplification means downline. For this purpose, it is sufficient to carry out a temporal staggering of the information relating to a first given polarisation and the information relating to a second polarisation crossed with the first polarisation.

Figure 3 illustrates an exemplary device according to the invention working with only one photodetector.

The emission means 21, 11, 01 may be identical to those described in the example of figure 2. This may also be the case with the collector optical system with its means 02 and 12 also as well as the element 22.

On the other hand, at the exit of one of the channels, it is possible to introduce a difference in optical path through a fibre 43a, and a coupler 43b enables a single photodetector 33 to collect all the temporally staggered signals. The length of optical fibre is calculated so as to make the signals succeed one another in an interval of time that is sufficiently short as compared with the frequency with which the water particles enter the volume of measurement.

At the exit of the photodetector 33, there is a single filter 64, a variable gain amplifier 74 and the computation processing unit 84.

The temporal staggering of the signals relating to the two crossed polarisations can also be initiated at the emission means as illustrated in figure 4. For this purpose, a birefringent element 31 enables the creation, from a single polarised beam, of two linearly polarised optical beams with perpendicular polarisations $P_{//}$ and $P_{\perp}$

The deflecting prism 21, directs the two incident beams with crossed polarisation into two slightly offset volumes of measurement V_1 and V_2. After passing into the collector optical system and its elements 02 and 12, and then passing into a polariser 52 with a polarisation P parallel to $P_{//}$, the back-scattered optical beams are detected by the photodetector 33.

The back-scattered optical beams are made up:

- for the beam with the initial polarisation $P_{//}$, of a high component relating to the liquid water drops and a weak component relating to the solid water drops;
- for the beam with the initial polarisation $P_{\perp}$, of two neighbouring components relating to the liquid and solid water drops.

In this exemplary device, the electronic circuitry downline from the photodetector may be of same type as that of the preceding example illustrated in figure 3.

In all the above examples, we have described a device applied against the internal face of a porthole window with which the aircraft is equipped. Generally the temperature probe is placed at another part of the

porthole window and the two types of information (relating to the severity of the icing conditions) are coupled in a central processing unit so that the severity of the icing conditions can be deduced therefrom.

According to one alternative of the invention, the device for the detection of icing conditions may be integrated directly into the temperature probe. Figure 5 illustrates an example in which a emission laser diode 51 emits an optical beam through the skin of the aircraft. The optical beam is propagated through the optical fibre FO_1 which is coupled to an emitter optical system 61 to emit an optical beam towards the volume of measurement V.

The optical beam back-scattered by the water particles is collected at a receiver optical system 63 (typically a lens with an index gradient) and propagated through the optical fibre FO_3 that goes through the skin of the aircraft and is coupled with a photodetector 53.

The two optical fibres FO_1 and FO_3 are mounted along the mast of the temperature probe MT.

With an emitted energy level of about one mW, a sighting distance of about 10 mm is attained. This is a sighting distance smaller than that of devices installed behind a porthole window. By making use of the protuberance that constitutes the temperature probe, it is thus possible to use a smaller sighting distance with lower power values and optical systems that are also smaller while at the same time being outside the boundary layer of the aircraft.

It must be noted however that a device of this kind (given the optical constraints) is adapted rather to applications in which it is not necessarily sought to obtain a very fine analysis of the icing conditions relying on a differentiation of behaviour in polarisation between supercooled water drops and ice crystals.

It may indeed be worthwhile to count only the water drops per unit of time to define a threshold beyond which the risks of icing become preponderant.

In all these devices, the information on the number of drops of water or the concentration of water in the air, coupled with the information on temperature, can be communicated to the aircraft pilot by a indicator that can pass from a green state to a red state in the least sophisticated devices, or by an indicator giving following information:

- severity of icing conditions
- type of water particles
- risk of icing

CLAIMS

1. Optical device for the detection of icing conditions, the device being placed on board an aircraft, characterised in that the device furthermore comprises:

- means to emit an optical beam to create at least one illuminated external volume of measurement through which there circulates a flow of air charged with water particles;
- a collector optical system for the collection of at least a part of the light beam back-scattered by the water particles (the external volume of measurement being located on the optical axis of said collector optical system);
- means for the photodetection of back-scattered optical beams;
- a device for the processing of the signal delivered by the photodetection means to compute the severity of the icing conditions;
- means for providing information on the icing conditions on the basis of the severity of the icing conditions.

2. Optical device for the detection of icing conditions according to claim 1, characterised in that the emission means comprise a laser diode.

3. Optical device for the detection of icing conditions according to one of the claims 1 or 2, characterised in that it comprises optical means for the differentiation of liquid water particles and solid water particles.

4. Optical device for the detection of icing conditions according to claim 3, characterised in that the laser diode is polarised and in that the collector optical system comprises a polarisation separator, delivering two optical beams with different types of polarisation.

5. Optical device for the detection of icing conditions according to claim 4, characterised in that the photodetection means comprise two photodetectors in order to collect the two optical beams with different types of polarisation.

6. Optical device for the detection of icing conditions according to claim 4, characterised in that collector optical system furthermore comprises means to introduce a difference in optical path for the two optical beams with different types of polarisation, the photodetection means comprising a photodetector to receive the two temporally staggered optical beams with different types of polarisation.

7. Optical device for the detection of icing conditions according to claim 3, characterised in that the emission means furthermore comprise a birefringent element for the creation, from the optical beam delivered by the laser diode, of two external volumes of measurement and two optical beams back-scattered by the water particles, the photodetection means comprising a photodetector to receive the two temporally staggered optical beams.

8. Optical device for the detection of icing conditions according to claim 1, characterised in that it is installed partially on the temperature probe of an aircraft and in that it comprises an optical fibre for the emission connecting the emission means integrated into the aircraft up to the external end of the temperature probe and an optical fibre for reception connecting the external end of the temperature probe up to the signal reception and processing means integrated into the aircraft.

9. Optical device comprising emission and detection means whose optical axes mutually form an angle known as a rainbow angle (of about 40°) making it possible to optimise the energy received by the detection means.

10. An optical device for the detection of icing conditions substantially as described hereinbefore with reference to the accompanying drawings and as shown in any one of those drawings.

The Patent Office

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INVESTOR IN PEOPLE

Application No: GB 9819471.5
Claims searched: 1-8

Examiner: Matthew Lincoln
Date of search: 17 December 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Int Cl (Ed.6): G01N 15/02, 21/47, 21/49, 21/53; G08B 19/02; B64D 15/20

Other: Online: WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	JP 020300688	(JAPAN RADIO) Abstract.	4, 5
X, Y	US 5641972	(BREDA) Whole document.	X: 1, 2, 3 Y: 4, 5

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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